

The University of Chicago

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GROWTH

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OF SEVERAL VARIETIES OF WINTER
WHEAT IN TRANSITION FROM DOR-
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A DISSERTATION SUBMITTED TO THE FACULTY
OF THE DIVISION OF THE BIOLOGICAL SCIENCES
IN CANDIDACY FOR THE DEGREE OF DOCTOR
OF PHILOSOPHY

DEPARTMENT OF BOTANY
1936

By
HILMER HENRY LAUDE

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CHICAGO, ILLINOIS

Reprinted from
JOURNAL OF AGRICULTURAL RESEARCH
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COLD RESISTANCE OF WINTER WHEAT, RYE, BARLEY, AND OATS IN TRANSITION FROM DORMANCY TO ACTIVE GROWTH¹

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INTRODUCTION

Winter killing often has been observed in winter wheat and other fall-sown cereals after spring growth has started. Severe injury may result in late winter or early spring from only moderately low temperatures that would cause little or no injury during midwinter. The practical importance of developing varieties that are resistant to killing during early spring is manifested by the serious losses frequently sustained by growers.

Extensive studies of the relative hardiness of winter cereals, particularly varieties of wheat in the hardened condition, have been made by Åkerman (1),³ Newton (19), Salmon (27), and others. Also a number of workers, including Suneson and Peltier (30), Newton and associates (19, 20, 21), and Martin (15) have studied the hardening changes that take place in wheat during the fall, from the active growing condition to the winter condition. In the investigations reported upon here the transition of winter cereals from the dormant winter condition to the active spring condition was studied with respect to the rate of change in cold resistance, the relative hardiness at various stages of early spring growth, and the association of certain conditions in the plants with cold resistance during the transition period.

REVIEW OF LITERATURE

Harvey⁴ recently prepared a very extensive and complete bibliography of the low-temperature relations of plants, including annotated references to 3,412 publications in this field. Abbe (2) summarized studies made prior to 1894 on the influence of cold on plants.

Salmon and Laude (28) have shown that the ability of a variety of winter wheat to survive the winter is of major importance in determining varietal adaptation. This fact is emphasized by Quisenberry and Clark (24), who point out that during the 26-year period from 1901 to 1926 an average of about 10 percent of the total winter wheat acreage of the United States was abandoned, largely because of winter injury. Marked differences in hardiness of varieties of winter wheat were shown by Clark, Martin, and Parker (5).

¹ Received for publication July 23, 1936; issued July 1937. Contribution no. 257 from the Department of Agronomy, Kansas Agricultural Experiment Station.

² The writer wishes to acknowledge the stimulating suggestions and helpful directions given by Dr. Charles A. Shull, plant physiologist, and other members of the Department of Botany, University of Chicago. Appreciation is expressed to C. W. Nauheim for assistance in collecting data.

³ Reference is made by number (*italic*) to Literature Cited, p. 916.

⁴ HARVEY, R. B. AN ANNOTATED BIBLIOGRAPHY OF THE LOW TEMPERATURE RELATIONS OF PLANTS. 223 pp. Minneapolis. 1935. [Mimeographed.]

Martin (15) found artificial freezing to be the best laboratory method for measuring the cold resistance of wheat. A close relation between the results of artificial freezing and winter injury in the field was demonstrated by Salmon (27). In experiments with oats Mather and Andersson (17) found artificial freezing to be a satisfactory way of determining comparative cold resistance and obtained a good correlation between the laboratory freezing tests and field results. Martin (14), working during the spring-growth period, found good agreement between injury in the field and injury by artificial refrigeration, and observed that it was possible to measure varietal differences in wheat by artificial freezing in both hardened and slightly hardened plants.

Rosa (26) concluded that cold resistance in plants is due to the increased water-retaining power of the cells, which enables them upon freezing to retain a larger proportion of their moisture content in the unfrozen condition.

Hooker (9) attributed the ability of plant tissue to hold water unfrozen when the plant is subjected to winter conditions to the pentosans, or even a specific pentosan. Hardy tissues contain less free water and more colloidal water than tender tissues. It has been suggested that the greater water content of tender tissue is due to an excess of free water. A positive correlation between hardiness and bound water was observed also by Lott (13).

Akerman (1), upon finding a close relation between cold resistance of wheat and its sugar content, developed the view that sugars have an important protective influence. Newton and Brown (21) have shown that sugar disappears gradually from winter wheat plants during the winter, the rate of loss being somewhat greater in nonhardy than in hardy varieties. Maximov (18) attributed greater endurance to cold to the accumulation of sugars and other soluble carbohydrates in the cell and to an increase in the water-retaining power of the cells in consequence of the accumulation of hydrophilic colloids.

Newton (19) found a close relation between the relative hardiness of varieties of wheat, the percentage of bound water, and the hydrophilic colloid content in the press juice of hardened tissues.

The hardening process, according to Harvey (8), is brought about by low temperature. During the hardening of wheats Martin (15) observed a decrease in moisture content and an increase in total solids in the sap. He also reported a positive correlation in a given variety between quantity of juice expressed and moisture content. Chandler (3) found that resistance to low temperature increased with an increase in sap density. As temperature decreased, Constantinescu (6) observed increases in total sugar content, osmotic pressure, and dry matter in winter wheat. Janssen (11) reported a positive correlation between total soluble carbohydrate compounds and winter hardiness. Dexter (7) concluded that hardening of plants is favored by conditions favoring the accumulation or conservation of carbohydrates and other reserve foods and that a high available carbohydrate supply is essential before the cold-temperature reaction of hardening of plants will occur in an efficient manner.

Roemer, Rudolf, and Lueg (25) measured total solids in the pressed juice of wheat leaves with the refractometer and found that varietal differences could readily be detected by this method in winter, when the plants were hardened. They found that the concentration of

solids in the juice was higher in cold than in warm weather and that varietal differences were greater in winter than in the spring. They concluded that the refractometer method parallels other methods in determining winter hardiness in varieties of wheat.

Dehydration of the cells is believed by Newton and Brown (22) to be the basic cause of the precipitation of proteins which occurs when tissue is killed by freezing. They found that sugar added to press juice decreased the precipitation and stabilized the juice protein.

Tottingham (31) found that respiration increased more than photosynthesis with an increase in temperature. Thus the result was a decrease in the carbohydrate-protein ratio. He concluded that temperature becomes the dominant factor in the regulation of metabolism by controlling the equilibrium between certain anabolic and catabolic reactions.

After intensive study of respiration of wheat plants at low temperature, Newton and Anderson (20) concluded that at -7° C. the rate of respiration in wheat varieties is inversely proportional to winter hardiness. They found the differentiation was indefinite early in the season but became increasingly sharp as the plants advanced into the fully hardened condition.

Howard (10) held that the rest period in plants is induced and maintained by the inhibition of the enzymes due to the accumulation of the products of their work and by cool weather. He attributed growth after the rest period to an increase in enzyme activity. According to Newton and Brown (23) the catalase activity of press juice of winter wheat leaves is directly related to the winter hardiness of the varieties.

Nauheim⁵ found that the loss of cold resistance of winter cereals in early spring was associated with increase in moisture and decrease in solids. Johnston (12) noted that the moisture content of peach buds increased during late winter and early spring and that the relation between moisture and effective temperatures was expressed as a straight-line equation.

MATERIALS AND METHODS

Winter wheat, rye, barley, and oats were grown at Manhattan, Kans., and were hardened outdoors by natural weather conditions. The hardened plants were moved to the greenhouse, where conditions favorable for growth were maintained. The experimental methods employed measured changes that occurred in the plants during the transition from the hardened, nearly inactive winter stage to the unhardened, very active spring stage. The characteristics and habits of growth assumed by the plants in the greenhouse were typical of those normally acquired in the field during the spring. It therefore appears reasonable to assume that the data obtained in these studies represent winter-spring transition conditions that occur normally in the field.

Studies were made with Rosen and Dakold winter rye, Tennessee winter barley, Sporen winter oats, and Kanred winter wheat. A description of the varieties of rye is given by Martin and Smith (16) and of Kanred wheat by Clark and Bayles (4). Rosen rye, C. I. no. 195,⁶ is slightly more winter-hardy under most conditions than the

⁵ NAUHEIM, C. W. THE RELATIVE LOSS OF HARDINESS IN WINTER CEREALS WHEN SUBJECTED TO WARM TEMPERATURES DURING WINTER AND EARLY SPRING. Thesis, Kans. State Col. 1934.

⁶ C. I. denotes accession number of Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture.

leading varieties of hard winter wheat. Dakold rye, C. I. no. 175, is very winter-hardy, perhaps as hardy as any known cereal. C. I. no. 3543 barley, used in these experiments, is a selection of Tennessee, a hardy variety of winter barley which is extensively grown. Sporen oats, C. I. no. 2506, is a variety of winter turf oats. Kanred C. I. no. 5146 is a red winter wheat that is relatively winter-hardy and is extensively grown.

The investigations included artificial freezing of hardened plants and of similar plants after they had been kept in the greenhouse for varying lengths of time or at different temperatures. In order to determine the comparative cold resistance in the hardened condition, plants were taken directly to the refrigerator from outdoors. The other plants in some of the experiments were taken into the greenhouse at one time and frozen at intervals thereafter, while in other experiments the plants were taken into the greenhouse at intervals and frozen simultaneously.

Adequate measurements could not be made by freezing all groups of plants at one time, because of too wide differences in cold resistance. Since some of the hardy groups might not be injured at all, while the less hardy groups might be killed entirely, it would have been impossible to measure definite differences in cold resistance among either the most hardy or the least hardy groups. Thus it was necessary so to plan the experiments that no freezing test included groups having more than a moderate range in hardiness.

For the freezing experiments, five plants were grown in 4-inch clay pots, the soil in which was prepared by mixing three parts of silt loam, one part of manure, and one part of sand. They were planted the latter part of September or early in October, which is about the normal time for fall seeding in the field at Manhattan. Soil moisture was maintained at about optimum. The barley and oats were covered with a muslin canvas during the coldest nights, to reduce the danger of winter killing.

The equipment described by Sellschop and Salmon (29) was used for the artificial freezing. Briefly it consists of a chamber in which cooling is effected by expansion of carbon dioxide. The temperature within the chamber is thermostatically controlled.

The freezing period was 12 hours, ending either at 8 a. m. or 8 p. m. After treatment, the plants were kept in the greenhouse and usually were observed for injury after 2 to 4 days. Injury was estimated and recorded as percentage of killed tissue in each pot. About 2 weeks after the plants were frozen the percentage of living plants in each pot was recorded. The experimental error was calculated for each experiment either by analysis of variance or by averaging the standard deviations of all the units. A close relation was found between the results expressed as injury and as survival, which agrees with the conclusion reached by Salmon (27). Unless otherwise stated, the freezing data are reported as the percentage of tissue killed by the treatment.

Moisture determinations were made with 5 g of fresh tissue which was dried to constant weight in a Freas oven at 95° C. The quantitative determinations of expressed juice were made by placing samples of tissue in a hydraulic press under pressure of 1,660 pounds per square inch, or 115 atmospheres, for 5 minutes. The tests were made in duplicate, with 3 g of green leaves. Each sample was wrapped in enough filter papers to absorb all the juice expressed from the leaves.

Usually six filter papers 9 cm in diameter were used for each sample. The filter papers were weighed before and after absorption of the pressed juice, the leaf tissue being discarded, and the filter papers with the pressed juice being immediately placed in weighing bottles to prevent loss by evaporation. The difference in the weight of the filter papers before and after pressing represented the amount of juice expressed from the sample.

Determinations of the total solids in the plant sap were made with the Abbe refractometer. The sap was obtained with a press devised for this work in which a small representative sample of the plant tissue was placed on a finely perforated plate through which a few drops of the juice were forced under high pressure.

The plants used in determining the moisture content, the quantity of expressed juice, and the solids in expressed sap, were grown outdoors in flats 20 inches square and 4 inches deep. Part of them were moved to the greenhouse at the beginning of an experiment, and samples for the several tests were taken at intervals to measure changes in the plants that might be associated with the progressive loss of hardiness. The soil for the flats was prepared in the same way as that for the pots. The seed was planted between September 27 and 29. About 125 plants were grown in each flat.

EXPERIMENTAL RESULTS ON LOSS OF COLD RESISTANCE

The loss of cold resistance associated with the change from outdoor winter environment to the greenhouse was studied in winter wheat, winter rye, winter barley, and winter oats in 2 years, 1932-33 and 1933-34. Kanred wheat, Tennessee barley, and Sporen oats were used in both seasons; Rosen rye was included the first year and Dakold rye the second.

Duplicate experiments, A and B, were run to obtain data on the rate of loss of hardiness. In each experiment 80 pots of plants were used, 20 for each of the four crops. Of these 20 pots, 4 were not placed in the greenhouse, 4 were placed in it for 12 hours, 4 for 24 hours, 4 for 36 hours, and 4 for 48 hours. The greenhouse was maintained at favorable growing conditions, the temperature averaging 67° F. Then all the 80 pots in each experiment were frozen at the same time at 8° for 12 hours, the ones used in experiment A on January 3 and those used in experiment B on January 8, 1933. The relative cold resistance of the different lots of each crop is shown by the freezing injury reported in table 1. The standard error of the mean was found to be 3.1 percent, from which it may be assumed that differences among the averages greater than 8.8 percent are statistically significant for odds 19:1.

It is apparent that the crops began to lose resistance to cold very soon after their removal to the greenhouse. A marked loss of hardiness had occurred at the end of 24 hours, and small but consistent changes were found within the first 12 hours. Thus the difference in freezing injury during the first 12 hours was 5.5 percent for wheat, 4.5 for rye, 6 for barley, and 2.5 for oats. At the end of 24 hours the differences had increased to 46 percent for wheat, 50 for rye, 53 for barley, and 44.5 for oats. It appears therefore that the change in cold resistance for the period from 12 to 24 hours was highly significant for each of the crops as was also the change from 24 to 48 hours.

A part of the first 12-hour period was required to warm the soil; this may account for the small change during the first period as compared with the second period. A portion of the first period may also have elapsed before the plants responded to the stimuli of the greenhouse environment. The freezing injury increased for all the crops in each of the remaining 12-hour periods, although in no case was the change as great as in the second period.

TABLE 1.—Cold resistance measured by freezing injury of winter cereals when hardened and after 12, 24, 36, and 48 hours in the greenhouse; frozen at 8° F. for 12 hours

Crop	Experiment	Percentage freezing injury in plants under different conditions				
		Hardened	After indicated number of hours in greenhouse			
			12	24	36	48
Kanred wheat.....	{ A.....	3	9	49	51	60
	{ B.....	3	8	49	59	76
	Average.....	3	8.5	49	55	68
Rosen rye.....	{ A.....	8	15	53	64	69
	{ B.....	4	6	59	68	89
	Average.....	6	10.5	56	66	79
Tennessee barley.....	{ A.....	15	19	53	66	80
	{ B.....	1	9	69	76	90
	Average.....	8	14	61	71	85
Sporen oats.....	{ A.....	29	35	75	76	85
	{ B.....	21	20	64	78	91
	Average.....	25	27.5	69.5	77	88

In another experiment cold-resistance changes in the first 4 days in the greenhouse were studied for Kanred wheat, Rosen rye, and Sporen oats. The procedure was the same as in the preceding experiment. This experiment was repeated five times between January 23 and February 2, 1933. The average freezing injury for the six experiments is given in table 2. The standard error was found to be 1.28 percent for the values given in the table. From this it may be considered that a difference of 3.6 percent is statistically significant.

TABLE 2.—Cold resistance measured by freezing injury of wheat, rye, and oats when hardened and after 1 to 4 days in the greenhouse; frozen at 12°–14° F. for 12 hours

Crop	Percentage of freezing injury in plants under different conditions				
	Hardened	After indicated number of days in greenhouse			
		1	2	3	4
Kanred wheat.....	8	30	51	63	82
Rosen rye.....	8	30	42	72	82
Sporen oats.....	67	73	76	73	94

Rosen rye and Kanred wheat were equally resistant to freezing injury in the hardened condition and after 1 day and 4 days in the greenhouse and were much alike at the other stages. They apparently lost hardiness at about the same rate. Sporen oats was much less resistant than the other crops in the hardened condition and lost resistance more slowly so that after 3 to 4 days it was injured only slightly more than the wheat and rye.

DAILY CHANGE IN COLD RESISTANCE OF KANRED WHEAT THROUGHOUT
TRANSITION

The data that have been presented indicate that cold resistance was lost quickly after the plants were placed in the greenhouse where the environment stimulated the winter-spring transition changes. Since considerable resistance to cold still remained after 4 days, additional experiments were made to determine the length of time acquired cold resistance could be retained in such an environment, and to determine the rate of loss over a longer period. The experiments were conducted during January, February, and March 1934. It was found necessary to freeze the plants in three groups since it was not possible to obtain differential freezing injury when plants in all stages of cold resistance from the hardened to the unhardened condition, were frozen simultaneously. One group included hardened plants and those that had been in the greenhouse from 1 to 6 days. Another group included plants that had been in the greenhouse from 5 to 12 days, and the third, those that had been in the greenhouse from 9 to 16 days. The average freezing injury of the plants in each of the groups is given in table 3.

TABLE 3.—Daily changes in cold resistance of hardened Kanred wheat for 16 days after transfer to the greenhouse

Condition of plants and time in the greenhouse (days)	Average ¹ percentage freezing injury in—		
	Group 1 frozen at 7° F.	Group 2 frozen at 18° F.	Group 3 frozen at 20° F.
Hardened.....	5		
In greenhouse:			
1.....	34		
2.....	50		
3.....	66		
4.....	78		
5.....	87	43	
6.....	96	50	
7.....		60	
8.....		58	
9.....		71	41
10.....		74	44
11.....		85	40
12.....		90	46
13.....			56
14.....			50
15.....			53
16.....			54

¹ Averages for 24 pots in groups 1 and 3 and 12 pots in group 2.

The values given in table 3 are averages of 24 pots in groups 1 and 3 and 12 pots in group 2. The standard errors are 1.6 percent for group 1; 5.8 for group 2; and 4.4 for group 3. Thus differences

necessary for odds as high as 19:1 are 5, 16, and 13 percent respectively in the three groups. Because of the wide difference in cold resistance the first group was frozen at 7° F., the second at 18°, and the third at 20°. The freezing time in each case was 12 hours. The rate of change throughout the entire period is shown in figure 1, the curves

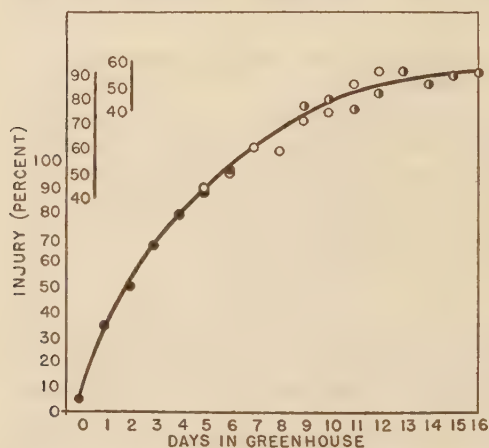


FIGURE 1.—Rate of loss of cold resistance in Kanred wheat throughout a 16-day period in the greenhouse. The plants were frozen in three groups on the basis of the length of time they had been in the greenhouse. The left scale of injury applies to the hardest group, frozen at 7° F., including hardened plants and those that had been in the greenhouse from 1 to 6 days. The middle scale is for the second group including plants that had been in the greenhouse from 5 to 12 days, which were frozen at 18°, and the right scale is for the third and least hardy group, frozen at 20° after having been in the greenhouse from 9 to 16 days. The curves for the three groups are superimposed on one another so as to give a continuous curve.

for the three separate groups being superimposed on each other so as to give a continuous curve.

It is apparent that the loss of cold resistance was very rapid in the first period, less so in the second, and very slow in the third. After 2 weeks the plants could withstand very little more freezing than if they had been grown continuously in the greenhouse, indicating that nearly all of the resistance to cold acquired outdoors had been lost. In other words, the transition from the hardy winter condition to the nonhardy spring condition had been practically completed.

RELATIVE RATE OF LOSS IN WHEAT AND OATS

An experiment similar to the one just described was made to compare the rates of loss of cold resistance in Kanred wheat and Sporen oats. Hardened wheat and oat plants that had been in the greenhouse from 1 to 7 days were frozen. Three separate tests with each crop were made between January 15 and 28, 1934. The data are shown in table 4.

TABLE 4.—Relative loss of cold resistance in hardened wheat and oats when placed in the greenhouse at 68° F.

Condition of plants and time in the greenhouse (days)	Percentage freezing injury for—	
	Kanred wheat, frozen at 7° to 11° F.	Sporen oats, frozen at 17° F.
Hardened.....	3	12
In greenhouse:		
1.....	33	16
2.....	61	29
3.....	74	47
4.....	80	51
5.....	79	64
6.....	95	76
7.....	96	84

The injury to wheat increased during the first 3 days from 3 to 74 percent, while the injury to oats increased from 12 to 47 percent. During the next 4 days wheat changed in cold resistance more slowly than oats. Although Kanred wheat, when hardened, is known to be much more resistant to cold than Sporen oats, the difference in the rate of change shown in this experiment would tend to make the two crops more nearly equal in hardiness at certain stages in the transition period.

COMPARATIVE RESISTANCE OF WINTER CEREALS AT INTERVALS DURING TRANSITION

The different rates at which cereals lost cold resistance in the experiments that have been reported suggest that the relative hardiness may vary at different times in transition from the dormant to the active stage of growth. To establish the comparative hardiness at several times in the transition period, wheat, rye, barley, and oats were frozen simultaneously when hardened and also at intervals after transfer to the greenhouse. Thirty-two pots of each of the four crops were moved into the greenhouse at one time, and eight of each crop were frozen immediately to measure the relation of the crops in the hardened condition. Similar lots were frozen after 6, 9, and 12 days to determine the relative cold resistance of the crops at each of those times. The experiment was repeated nine times at each stage of hardiness between January 6 and March 5, 1934; in the course of this work 5,760 plants were tested. Additional plants were tested on the third day in some of the experiments and on the 15th day in others.

The hardened crops differed widely in cold resistance since the average freezing injury of Dakold rye was 10 percent, as compared with 38 for Kanred wheat and 85 percent for Tennessee barley and Sporen oats, as shown in table 5 and illustrated in figure 2. The standard error of this experiment for the values given in the table was 1.65 percent; from this it was found that a difference of 4.7 percent between freezing injuries of crops within a stage is significant for odds of 19:1.

The crops became more nearly equal in cold resistance at each successive test until at the end of 9 days the greatest difference (that between rye and barley) was only 13 percent. Little difference in cold resistance was found when the crops had been in the greenhouse

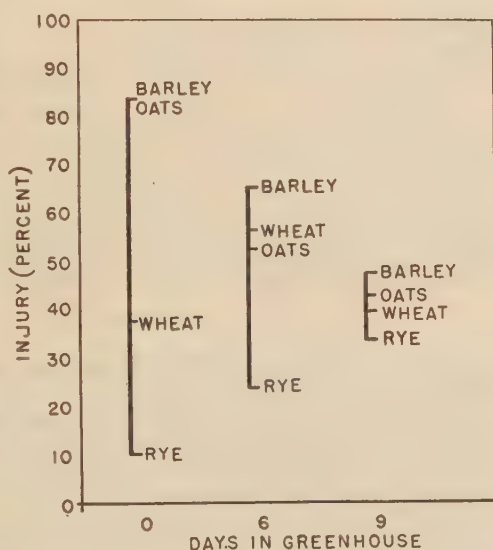


FIGURE 2.—Comparative cold resistance of wheat, rye, barley, and oats when hardened and after 6 days and 9 days in the greenhouse.

12 and 15 days. The data show that for these crops in the hardened condition the range of injury was 75 percent, whereas at the end of 6 days in the greenhouse it had decreased to 42 and in 9 days to 13 percent.

Table 5.—*Comparative cold resistance of cereals at intervals in transition from dormancy to active growth, when hardened and after 6, 9, and 12 days in the greenhouse*

Crop	Percentage of freezing injury in plants under different conditions			
	Hardened, frozen at 5°-7° F	After indicated number of days in greenhouse		
		6, frozen at 14°-16° F	9, frozen at 17°-19° F	12, frozen at 19°-21° F
Kanred wheat.....	33	57	40	50
Dakold rye.....	10	24	34	39
Tennessee barley.....	85	66	47	59
Sporen oats.....	85	53	43	53

Although hardened Sporen oats was much less resistant to cold than Kanred wheat the two crops were not significantly different after having been in the greenhouse 6 days. Due to transition changes the hardy Dakold rye became nearly as susceptible to freezing as Sporen oats in 9 days in the greenhouse. It seems evident therefore that the transition changes proceeded more rapidly in the hardy crops, rye and wheat, than in the less hardy, barley and oats.

RELATION OF TEMPERATURE TO RATE OF LOSS

In the experiments reported in the preceding pages the principal difference between the outdoor and greenhouse environments was one of temperature. Soil moisture was ample in both cases, and the length of the daily light was nearly the same. The quality and intensity of the light, the atmospheric moisture, and other environmental conditions appeared not to have been so dissimilar as to account for the marked losses in cold resistance that were noted during the first few days the plants were in the greenhouse.

In order to determine the effects of temperature specifically an experiment was conducted in which four pots of hardened wheat plants were moved to each of two greenhouses on 7 successive days. The temperature in one of the houses was maintained at an average of 80° F. and that in the other at 60°. On the eighth day eight pots of hardened plants, together with those that had previously been placed in the two greenhouses, were all frozen at the same time. Similar experiments were conducted with rye, barley, and oats. The crops were frozen between January 14 and 18, 1934. The rye was frozen at 4°, the wheat at 7°, the barley at 16°, and the oats at 17°.

As is shown in table 6, the cold resistance decreased more rapidly in the plants maintained at 80° F. than in those held at 60°. The standard error for the values reported in the table was 2.7 percent; thus the smallest difference that is statistically significant for odds of 19:1 is 7.6 percent.

The loss in resistance in the warm house was as great in 1 day as that in the cool house in 2 days. The data for longer periods fluctuate

considerably, but in general the difference in resistance that developed in the first 2 days was continued. It appears therefore that temperature is a major factor in determining the loss in cold resistance and that the rate of change is associated with the amount of heat.

RELATION BETWEEN CERTAIN CONDITIONS IN WINTER CEREALS AND COLD-RESISTANCE CHANGES DURING TRANSITION

Changes in water content, in amount of plant juice that may be expressed with a given pressure in a given time, and in refraction of the plant sap were studied in relation to the cold resistance of the plants during transition from the dormant to the active stage of growth.

TABLE 6.—*Influence of temperature alone on rate of loss of cold resistance in wheat, rye, barley, and oats*

Condition of plants and time in greenhouse (days)	Average percentage freezing injury after greenhouse temperatures of—	
	80° F.	60° F.
Hardened.....	6	6
In greenhouse:		
1.....	33	13
2.....	52	36
3.....	57	59
4.....	77	61
5.....	73	67
6.....	87	78
7.....	96	71

The changes were studied in 1933 for 7 days and in 1934 for as long as 15 days after the plants were moved to the greenhouse. For these experiments, plants grown and hardened in flats outdoors were tested at the time they were moved into the greenhouse in February of each year and at intervals thereafter. The samples in 1934 were comparable as to time of sampling and as to the plants tested. In 1933 the samples for water content and expressed juice were comparable, but those for refraction of sap were taken from other flats at another time. In the first experiment the water content and expressed juice were determined in leaves of hardened wheat, rye, and barley and after the plants had been in the greenhouse 1, 2, 3, 5, and 7 days. Similarly, wheat and barley were tested for refraction of sap. In the second experiment water content, expressed juice, and refraction of sap were studied in comparable samples of wheat, rye, barley, and oats when hardened and at 3-day intervals after the plants had been moved to the greenhouse. The data are shown in tables 7 and 8 and are illustrated in figures 3 to 8.

TABLE 7.—*Water content, expressed juice, and refraction of sap in leaves of cereals when hardened, and after 1, 2, 3, 5, and 7 days in the greenhouse*

Determination and crop	Data for plants under different conditions					
	Hardened	Results after indicated number of days in greenhouse				
		1	2	3	5	7
Water content:						
Kanred wheat.....percent.....	74.5	76.7	80.2	82.7	84.0	85.1
Rosen rye.....do.....	76.2	80.0	81.9	82.6	84.3	84.8
Tennessee barley.....do.....	77.7	80.1	82.6	84.3	84.8	86.0
Average.....do.....	76.1	78.9	81.6	83.2	84.4	85.3
Expressed juice:						
Kanred wheat.....do.....	23.2	25.3	25.6	29.2	32.2	35.8
Rosen rye.....do.....	23.1	26.7	27.1	28.1	30.9	31.8
Tennessee barley.....do.....	23.2	24.1	25.0	29.5	31.8	36.4
Average.....do.....	23.2	25.4	25.9	28.9	31.6	34.7
Refractive index of sap:						
Kanred wheat.....do.....	1.3440	1.3400	1.3402	1.3401	1.3390	1.3389
Tennessee barley.....do.....	1.3475	1.3421	1.3415	1.3404	1.3366	1.3372
Average.....do.....	1.3458	1.3411	1.3409	1.3403	1.3378	1.3381

TABLE 8.—*Water content, expressed juice, and refraction of sap in leaves of cereals when hardened, and at 3-day intervals after transfer to the greenhouse*

Determination and crop	Data for plants under different conditions				
	Hardened	Results after indicated number of days in greenhouse			
		3	6	9	12
Water content:					
Kanred wheat.....percent.....	77.2	81.2	83.5	84.1	84.6
Dakold rye.....do.....	78.2	81.6	84.3	83.6	83.2
Tennessee barley.....do.....	78.3	82.9	84.6	85.4	86.1
Sporen oats.....do.....	74.9	79.1	80.4	86.1	83.8
Average.....do.....	77.2	81.2	83.2	84.8	84.4
Expressed juice:					
Kanred wheat.....do.....	25.1	31.7	34.8	38.4	45.4
Dakold rye.....do.....	28.8	33.4	34.3	37.8	41.3
Tennessee barley.....do.....	27.0	33.3	36.4	43.8	49.2
Sporen oats.....do.....	24.8	30.0	32.0	37.7	44.4
Average.....do.....	26.4	32.1	34.4	39.4	45.1
Refractive index of sap:					
Kanred wheat.....do.....	1.3483	1.3380	1.3395	1.3367	1.3351
Dakold rye.....do.....	1.3450	1.3400	1.3404	1.3369	1.3358
Tennessee barley.....do.....	1.3472	1.3375	1.3380	1.3356	1.3354
Sporen oats.....do.....	1.3533	1.3407	1.3402	1.3364	1.3349
Average.....do.....	1.3484	1.3391	1.3395	1.3364	1.3353

WATER CONTENT OF PLANTS

Barley contained slightly more moisture than rye or wheat at comparable stages throughout both experiments. Wheat had a little less moisture than rye when hardened, and this difference was maintained for 2 days in the greenhouse. After this period the two crops contained nearly equal amounts. The water content of the oats was less than for any of the other crops during the first 6 days in the greenhouse.

The water content of wheat, rye, and barley increased at daily intervals for the first 3 days in the greenhouse, the average change being greatest on the first day and less each day thereafter. Tests made at 3-day intervals show an increase in percentage of water during the first period amounting to 3.4 for rye, 4.0 for wheat, 4.2 for oats, and 4.6 for barley and an increase about one-half as great during the next 3 days. The change from 6 to 9 days was less regular although in general the moisture content increased. There was practically no change in moisture after 9 days, as was shown by tests made 12 and 15 days after the plants were placed in the greenhouse.

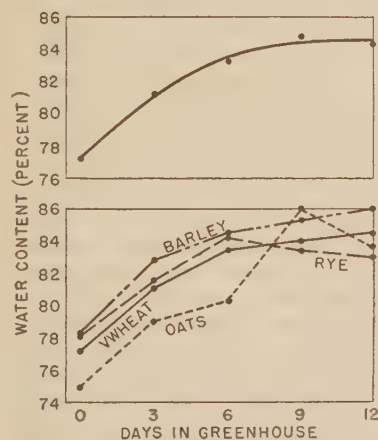


FIGURE 4.—Water content of leaves of cereals when hardened, and at 3-day intervals after being placed in the greenhouse. The upper curve is fitted to the average data.

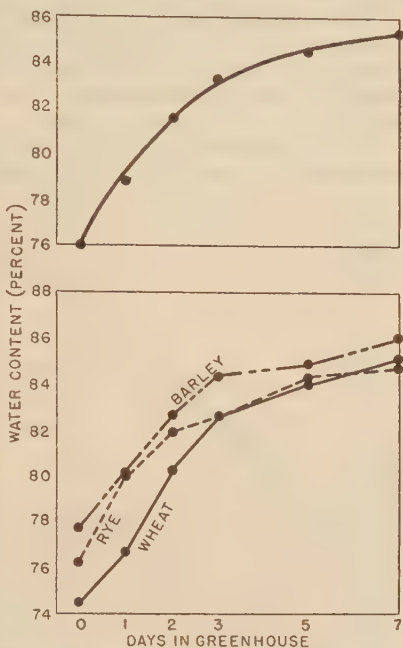


FIGURE 3.—Rate of increase of water in leaves of cereals when hardened, and when transferred to the greenhouse. The upper curve is fitted to the average data.

Representative samples taken at intervals showed that the rate of increase of water in plants and the rate of decrease of cold resistance were similar during the first few days that plants were in the greenhouse. After about 9 days, however, the moisture content remained nearly constant, whereas the plants continued to lose resistance although at a slower rate. It might be assumed that the increase in moisture explained the loss of cold resistance during the first 9 days, but some other cause must be sought to account for subsequent changes.

QUANTITY OF EXPRESSED JUICE

The amounts of juice expressed from the leaves increased in every case with

the length of time the plants were in the greenhouse. In general, the increase was somewhat less in rye than in the other crops which were nearly equal. The smoothed curve drawn to fit the average percentage of expressed juice for all crops is essentially a straight line in both experiments, indicated a uniform rate of increase. Results of other experiments indicated that the original rate of increase was maintained as long as 15 days after hardened plants were placed in the greenhouse.

A comparison of figures 5 and 6 with figures 3 and 4 shows that whereas the quantity of expressed juice continued to increase at its original rate the increase in water content was less after the first 3 days and practically ceased at the end of 9 days. In other words, the increase in moisture was curvilinear, whereas that in expressed juice was linear.

Changes in expressed juice during the first part of the period may be explained as the result of increase in the water content of the tissue. However, since water remained constant during the latter part of the transition, some other factor or factors are evidently involved. Increase in expressed juice and decrease in cold resistance progressed simultaneously during the transition.

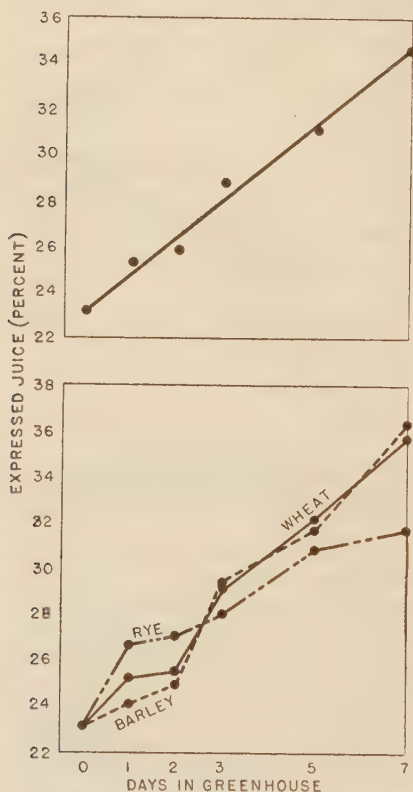


FIGURE 5.—Increase in the amount of juice expressed from leaves of cereals when hardened, and when transferred to the greenhouse. The upper curve is fitted to the average data.

REFRACTION OF PLANT SAP

The refraction of the sap was determined as a measure of the relative amounts of total solids in the juice of the plants. The refractometer readings indicate a marked decrease in solids of wheat and barley during the first day that plants were in the greenhouse, as illustrated in figure 7. Although the data fluctuate somewhat there was a definite downward trend in refraction values after that time.

Each of the cereals included in the experiment in which tests were made at 3-day intervals, showed a large reduction in the concentration of solids in the sap during the first 3-day period in the greenhouse. The results of tests at daily intervals suggest that most of this change probably took place during the first day. The reduction in the average refractometer readings was more than twice as much in the first 3 days after the plants were moved to the greenhouse as in the next 9 days, indicating a further but more gradual downward trend in solids. In other experiments it was found that no significant reduction in solids took place after hardening plants had been in the greenhouse 9 days.

Differences in refraction, indicating reductions in total solids of the plant sap, were associated with the increases in water content that have been presented. Most of the change with respect to both solids and water content took place within the first 6 days and very little after the ninth day that the plants were in the greenhouse. Concentration of solids in the sap was not associated with the amount of expressed juice, which, as has been shown, increased at a linear rate throughout the transition.

DISCUSSION AND CONCLUSIONS

Temperature is probably the major factor influencing hardness changes of winter cereals in the field, although light and moisture are of some importance. In the experiments reported here the significant changes in the artificial environment were primarily changes in temperature. Moisture was maintained at about the optimum and therefore probably was not a differential factor except as its utilization might have been influenced by temperature or perhaps other factors.

Light conditions in the greenhouse are known to be different from those outdoors, but in these experiments the plants that were directly compared were either subjected to the same light conditions or were in different light for so short a time that probably the experimental data were not materially influenced. The same may be said regarding the influence of biological conditions, which are known to be different in the greenhouse and outdoors in winter. Under field conditions these factors might change concomitantly with hardness in early spring. The small amount of soil to be affected by the temperature change also accounts in part for the quick response of plants in the experiments. It appears reasonable to assume that in these experiments the transition changes occurred more rapidly but otherwise were reasonably comparable with what takes place in the field when the plants change from winter dormancy to active spring growth. In the field the transition probably requires as much as 1 or 2 months, whereas in the greenhouse the plants lost nearly all of their acquired cold resistance in 2 weeks.

The results indicate that the rate at which a crop loses resistance to cold is roughly proportional to the degree of hardening. Thus a fully hardened plant will change rapidly when the environment becomes favorable for growth, and as resistance is lost the rate of change will decrease.

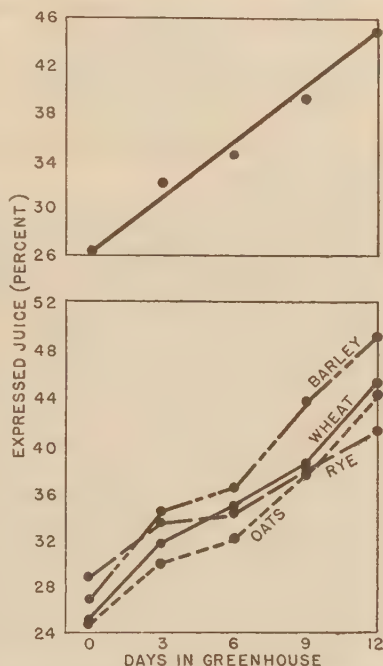


FIGURE 6.—Increase in the amount of juice expressed from the leaves of cereals when hardened, and at 3-day intervals after being placed in the greenhouse. The upper curve is fitted to the average data.

The studies indicate that the moisture content of plants increases as they lose their hardiness to cold which is the reverse of the water changes occurring while plants become hardened to cold as reported by Newton and Brown (21). The increase in pressed juice during

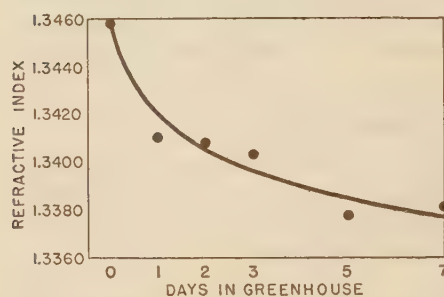


FIGURE 7.—Reduction of total solids in leaves of hardened wheat and barley after transfer to the greenhouse as measured by the refractive index of the sap.

the moisture content of the plants during the latter part of the transition changes.

In general, the quantitative changes with respect to solids appear to be associated inversely with changes in water content. This suggests that the phenomenon is chiefly one of dilution brought about by the increasing amount of water in the tissue. However, there is indication that the solids were reduced more during the first day than might be accounted for by the increase in water. The greenhouse environment may have stimulated respiration, with the consequent utilization of solids before an equivalent production of solids was brought about by photosynthesis, the temporary net result of which would be a lower solid content than would be caused by dilution alone.

Investigations of Rosa (26) and others have shown that changes which occur while plants acquire hardiness are principally dependent directly or indirectly upon water changes. The present investigations indicate that when plants lose hardiness under the stimulation of favorable environment the changes in cold resistance also are associated with moisture changes. The loss of cold resistance for the entire transition period may be explained on the basis of water conditions, assuming that bound water was changed to free water. Such a change would make more water available for plant

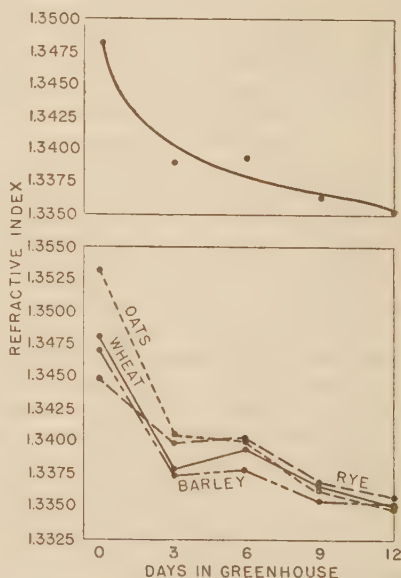


FIGURE 8.—Total solids in leaves of cereals when hardened, and at 3-day intervals after being placed in the greenhouse as measured by the refractive index of the sap. The upper curve is fitted to the average data.

growth without increasing the total water content of the tissue. Thus there might be an increase in the amount of available water corresponding with a decrease in cold resistance until the plant had lost all of its acquired hardiness.

SUMMARY

Changes in cold resistance during transition from dormancy to active growth were studied in winter cereals including wheat, rye, barley, and oats for two seasons, 1932-33 and 1933-34. The crops were planted in the fall in pots or flats, were grown outdoors and hardened by natural winter weather. The transition changes were induced when winter-hardened plants were transferred to a greenhouse where a favorable growth environment was maintained. Relative cold resistance and changes in resistance were measured by artificially freezing the plants at various stages in the transition. Changes in water content of the plants, expressed juice, and refraction of plant sap were studied in relation to changes in cold resistance.

Transition under the control provided in the experiments was faster but otherwise apparently comparable to winter-spring transition in the field. Temperature is thought to have been the chief factor influencing the rate of transition.

The change in cold resistance was found to proceed at a decreasing rate except for a short period of about 12 hours immediately after the plants were placed in the favorable growth environment. This initial time was apparently needed for the soil to warm and for the plants to respond to the temperature. However, as soon as the plants were stimulated into activity their cold resistance decreased very rapidly. The rate of change was greatest during the first part of the transition and gradually became slower until after 2 weeks little change was taking place.

Dakold rye was found to be considerably more resistant to cold than Kanred wheat, which in turn was much more resistant than Tennessee barley and Sporen oats in the hardened condition. However, when the crops had been in the favorable growth environment of the greenhouse 9 days little difference in cold resistance remained among them. All of the crops had lost resistance, and evidently the hardy rye had lost more than the others and wheat more than barley and oats.

Water content of the plants increased and total solids in the sap decreased during the transition. The changes were rapid at first and then slower until about the ninth day, after which little change took place with respect to either condition.

The amount of juice expressed from leaves increased at a constant rate throughout the transition period, suggesting that a change of bound water to free water continued after the maximum water content was attained.

Cold-resistance changes were negatively associated with water content, refraction of sap, and pressed juice during the first half of the transition period and similarly associated with pressed juice during the last half of the period.

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COMPARISON OF THE COLD RESISTANCE OF SEVERAL VARIETIES OF WINTER WHEAT IN TRANSITION FROM DORMANCY TO ACTIVE GROWTH¹

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INTRODUCTION

A recent study by the author (5)³ relative to the cold resistance of winter cereals during transition from dormancy to the active stage of growth suggested that varieties of a crop may differ in the rate at which hardiness is lost in the winter-spring transition. Since considerable winter-killing occurs in early spring when temperatures are only moderately low, it is important that wheat and other fall-sown cereals be spring-hardy as well as winter-hardy. The relative cold resistance in the hardened condition is well established for many of the older and for some of the newer varieties of winter wheat. The comparative hardiness during transition from the dormant condition of winter to the active growing condition of spring is less well known. The study reported in this paper was made to determine the differences between varieties of winter wheat with respect to the rate of loss of hardiness and the comparative cold resistance at intervals in the winter-spring transition.

REVIEW OF LITERATURE

A review of the literature dealing with winter hardiness, particularly as it relates to transition changes, has been given by the writer (5). Changes in the relative hardiness rank of varieties of wheat during the winter were noted by Suneson and Peltier (7) and were attributed to hardening adjustments. Anderson and Kiesselbach (1) suggest differential adjustment to environmental conditions among varieties of wheat as a possible explanation for occasional reversals of varietal hardiness in different seasons under field conditions. Hill and Salmon (4) noted that varieties of wheat when artificially frozen reacted differently, the type of reaction depending upon whether the plants were field-hardened or only slightly hardened.

In a study of the Montmorency cherry, Gardner (3) found variations in cold hardiness of flower buds at different stages in their development. Susceptibility to freezing injury at any of the stages was not closely correlated with the degree of differentiation or development that had been attained, nor was susceptibility at one stage correlated with that at another stage.

¹ Received for publication Aug. 13, 1936; issued July 1937. Contribution no. 263 from the Department of Agronomy, Kansas Agricultural Experiment Station.

² The writer wishes to acknowledge the stimulating suggestions and helpful directions given by Dr. Charles A. Shull, plant physiologist, and other members of the Department of Botany, University of Chicago.

³ Reference is made by number (italic) to Literature Cited, p. 925.

MATERIALS AND METHODS

The experimental methods were in general the same as those used by the author (5) in a study of different winter cereals in the transition period. In the present investigation six varieties of winter wheat (*Triticum aestivum* L., syn. *T. vulgare* Vill.) planted in late September were grown in pots out of doors at Manhattan, Kans. In midwinter, when the plants probably had attained their maximum resistance to cold, eight pots of each variety were transferred to the greenhouse and the plants were artificially frozen. At the same time other pots were transferred to the greenhouse and similar groups of the six varieties were frozen at the end of 1, 2, 3, 4, 6, and 10 days. In this way the relative cold resistance of the varieties was directly compared at intervals during transition to the active stage, which was stimulated by the favorable growth environment maintained in the greenhouse. These tests were repeated between January 19 and 29, 1935. The varieties, which are described by Clark and Bayles (2), were Minturki, C. I. No. 6155;⁴ Kanred, C. I. No. 5146; Quivira, C. I. No. 8886; Tenmarq, C. I. No. 6936; and Blackhull, C. I. No. 6251, which are varieties of hard or semihard red winter wheat, and Harvest Queen, C. I. No. 6199, a soft red winter wheat.

The relative injury expressed as an index was determined by a method similar to the one used by Quisenberry (6) in which both the estimate of frozen tissue and the percentage survival were taken into account.

EXPERIMENTAL RESULTS

The comparative freezing injury of the six varieties in the hardened condition and at intervals after the plants were transferred to the greenhouse is reported in table 1. The data permit direct comparisons only in the same column; that is, between varieties that were frozen at the same time.

TABLE 1.—Comparative cold resistance of varieties of wheat measured by freezing injury when hardened and at intervals after transfer to the greenhouse

Variety	Average index of freezing injury at different stages						
	Hardened	After indicated number of days in greenhouse					
		1	2	3	4	6	10
Minturki.....	72	69	80	82	77	72	75
Kanred.....	76	69	80	85	82	69	65
Quivira.....	79	77	82	82	80	75	73
Tenmarq.....	80	75	82	82	76	70	72
Harvest Queen.....	83	76	81	77	74	60	59
Blackhull.....	85	81	87	84	82	74	75
Average.....	79	75	82	82	79	70	70

The standard error for the values given in table 1 is 0.64 percent, from which it was found that within a stage any difference between varieties as great as 1.8 percent is significant for odds of 19:1. The results are illustrated by the plants in figure 1 and are shown graphi-

⁴ C. I. denotes accession number of the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture.

cally by the varietal curves in figures 2 and 3. The rate-of-loss curve for wheat which the author (5) derived experimentally was used as the basis for the general trend in figures 2 and 3. The varietal curves were located by first superimposing upon the rate curve the average



FIGURE 1.—Comparative recovery of six varieties of wheat frozen at three transition stages: *A*, Frozen in the hardened condition; *B*, frozen after being in the greenhouse 6 days; *C*, frozen after being in the greenhouse 10 days. Pot no. 1 is Minturki; no. 2, Kanred; no. 3, Quivira, no. 4, Tenmarq, no. 5, Blackhull, and no. 6, Harvest Queen. Photographed about 7 weeks after freezing.

injury index at each stage in the present experiment and then locating the position of each variety by measuring its experimental deviation in terms of scale deviations.

In the hardened condition the most cold-resistant variety was Minturki, followed in order by Kanred, Quivira, Tenmarq, Harvest

Queen, and Blackhull. Quisenberry⁵ has furnished data showing the field survival of these varieties in winter-hardiness nursery tests at a considerable number of stations in the Great Plains area from 1920 to 1935. In these tests Harvest Queen was included for 57 station years, Quivira for 116, Tenmarq for 181, and the others for more than 250. The relative average survival was 118 for Minturki, 103 for Kanred, 87 for Harvest Queen, 84 for Quivira, 83 for Tenmarq, and 79 for Blackhull. Thus it appears that the artificial freezing tests

gave essentially the same results as extensive field experiments in measuring the relative hardiness of these varieties. The slightly higher standing of Harvest Queen in the winter-hardiness nursery tests may have been due to its superior spring hardiness, which was not a factor in the artificial experiments with hardened plants.

At the end of the first day in the greenhouse the order of the varieties was about the same as that of the hardened plants at the beginning of the experiment. After 2 days the varieties were about equally resistant except Blackhull, which was less hardy. At the end of 3 days Harvest Queen possessed the greatest resistance; the other varieties were nearly alike in this respect. Thus in 2 or 3 days after transfer to the greenhouse, varieties

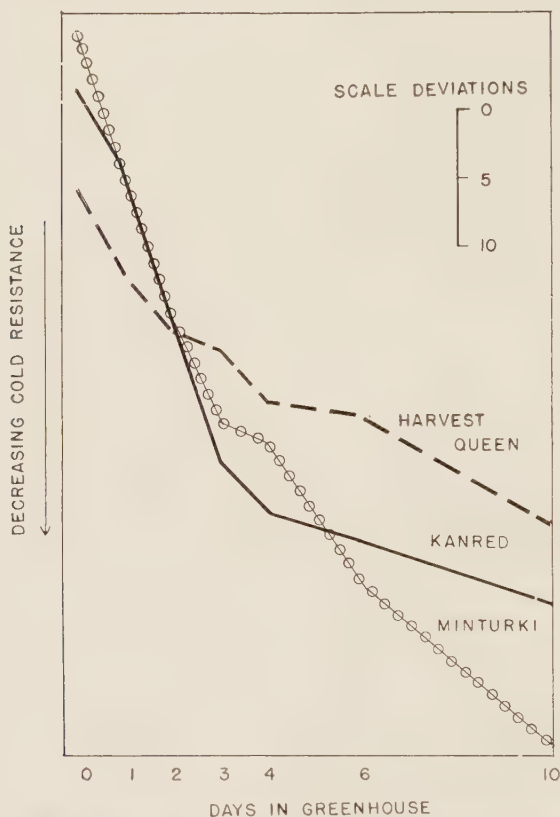


FIGURE 2.—Relative cold resistance of Minturki, Kanred, and Harvest Queen, showing reversal of varieties in transition from dormancy to active growth.

which had differed greatly in cold resistance became about equally hardy owing to different rates of transition.

The rate of transition in Quivira and Tenmarq was about the same, and since these varieties were similar when hardened, they did not differ much at any time during the 10-day period after transfer to the greenhouse. At the end of 6 days Blackhull appeared to be slightly harder than Quivira. Although Minturki was the most resistant variety at the beginning of the experiment, transition apparently proceeded fast enough to make it less resistant after 10 days than the other varieties except Blackhull, which it equaled in hardiness.

⁵ Personal letter.

The relative cold resistance of Minturki, Kanred, and Harvest Queen at the different stages illustrates varietal reversal in hardiness (fig. 2). Because of the slow rate of change in Harvest Queen it was more resistant than the other varieties at the end of 3 days and continued to be significantly hardier thereafter. Minturki, on the other hand, changed from the hardiest to the least hardy of the three varieties within 6 days after transfer to the greenhouse, while Kanred was intermediate both when hardened and at the end of 6 and 10 days after transfer.

The relatively slow rate of change in Harvest Queen has been shown in other studies. In one series of experiments hardened plants of Kanred and Harvest Queen were placed in the greenhouse for 3 consecutive days. On the fourth day the hardened plants and plants of both varieties previously taken to the greenhouse were artificially frozen at the same time. Thus a direct comparison of cold resistance was made among the four stages and between the varieties. The experiment was conducted 10 times between January 18 and February 6, 1933. The average survival of plants is shown in table 2.

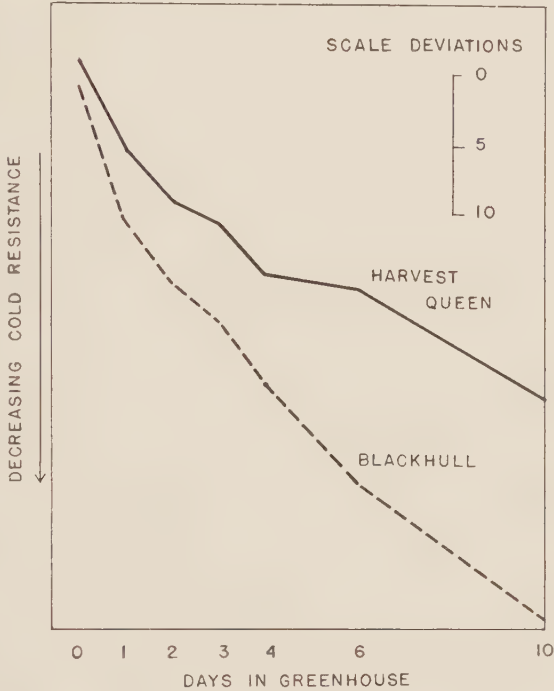


FIGURE 3.—Relative cold resistance of Harvest Queen and Blackhull, illustrating slower transition in the variety possessing the greater midwinter hardiness.

TABLE 2.—Changes in the relative cold resistance of Kanred and Harvest Queen during transition as shown by artificial freezing when hardened and after 1, 2, and 3 days in the greenhouse

Variety	Percentage survival of plants in different conditions			
	Hardened	After indicated number of days in greenhouse		
		1	2	3
Kanred.....	79	51	12	3
Harvest Queen.....	70	52	24	16

In the hardened condition the difference was 9 percent in favor of Kanred. After 1 day in the greenhouse the resistance of the two

varieties was about the same, but at the end of 2 and 3 days the differences in favor of Harvest Queen were 12 and 13 percent, respectively. The standard error of these experiments was 1.7 percent, from which it was determined that differences greater than 4.8 percent among the values reported in the table are statistically significant. Comparisons may be made among the different stages as well as between the varieties.

In another study during January and February 1934, comparable plants of Minturki and Harvest Queen were artificially frozen at the same time in nine experiments. The average survival of hardened plants of Minturki was 67 percent and of Harvest Queen 51 percent, a difference of 16 percent in favor of Minturki. When the plants were frozen after having been in the greenhouse for 6 days, the survival of Minturki was 63 percent and that of Harvest Queen 68 percent, a difference of 5 percent in favor of Harvest Queen. Thus during 6 days of greenhouse environment the relative resistance of the varieties was reversed. The high statistical significance of the varietal change is shown by the fact that the standard error of the experiment was 2.7 percent, from which it was found that a difference of 7.6 percent has odds of 19:1.

The experiments indicate a tendency for the hardy varieties to change faster during transition than the less hardy ones. However, the results with Harvest Queen and Blackhull illustrated in figure 3 show that transition was slower in the hardier variety. In that case the superiority of Harvest Queen at the beginning of the experiment is shown by a difference of 2 in the freezing index. The difference had increased to 5 at the end of the first day, to 6 the second, 7 the third, 8 the fourth, 14 the sixth, and to 16 the tenth day.

DISCUSSION AND CONCLUSIONS

Changes in the relative cold resistance of several varieties of winter wheat were found in the transition from the dormant to the active stage of growth. Certain varieties that possessed a marked degree of resistance when hardened were not superior, and in some cases were inferior, in this respect several days after spring growth began. Although in general the hardiest varieties lost resistance to cold most rapidly in the favorable growth environment of the greenhouse, the reverse was true in the comparison of Harvest Queen and Blackhull. It is apparent, therefore, that the rate at which cold resistance is lost in varieties of winter wheat in the winter-spring transition is not necessarily associated with the degree of cold resistance in the hardened condition.

Winter-killing losses in wheat during the spring may be reduced by the development of varieties with superior resistance after spring growth starts. No physiological reason is known which would prevent the possibility of finding or developing a hardy variety of winter wheat that will retain a relatively high degree of resistance into the spring growth period, and thus be spring-hardy as well as winter-hardy. The characteristic of slow change in cold resistance from winter to spring has been given little consideration, but with more study it seems probable that among the hardy varieties now known one or more may be found to be highly resistant in early spring as well as in winter. If such a search fails, it should be possible to combine

midwinter hardiness with spring hardiness by crossing such a variety as Harvest Queen with varieties that are highly resistant in midwinter.

No evidence was found in these investigations which indicated a relation between time of maturity and rate of change in cold resistance in the winter-spring transition. It might be thought that early-maturing varieties, because of the shorter time required for them to reach maturity would quickly lose their resistance to cold when the transition changes begin. However, the short time for spring growth apparently is not antagonistic to the maintenance of cold resistance. Quivira ripens 2 or 3 days earlier than Tenmarq, but loses its cold resistance at about the same rate. Kanred is about 2 days earlier than Minturki, but loses its resistance more slowly. Minturki and Harvest Queen ripen at about the same time and later than the other varieties studied. These varieties represent the extremes in rate of change in cold resistance, Minturki changing most rapidly and Harvest Queen most slowly. An explanation for the lack of association between time of maturity and rate of transition may possibly be found in the hypothesis that developmental changes in the life cycle of the plant can proceed independently of cold-resistance changes when spring growth is initiated.

SUMMARY

The comparative cold resistance of six varieties of winter wheat—Minturki, Kanred, Quivira, Turkey, Blackhull, and Harvest Queen—was studied during transition from the winter to the spring stage of growth which was induced by transferring naturally hardened plants in the winter from outdoors to the greenhouse.

Although the loss of cold resistance was usually more rapid in the varieties possessing greater midwinter hardiness, the contrary was also found.

Harvest Queen lost its resistance to cold more slowly than any of the other varieties studied, and thus it retained a relatively high degree of resistance into the spring-growth stage. This character is probably important in protecting the crop against injury from early spring freezes and may well be considered in the improvement of winter wheat.

No relation between rate of transition and time of maturity was found among the varieties studied.

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